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The increasing cost of fuel consumed by major weapon systems is a continuing concern for the Department of Defense (DoD). Because fuel costs are growing more rapidly than other operating and Support (O&S) costs, they are consuming a growing fraction of the O&S budget. One solution to the problem is to place greater emphasis on acquiring energy efficient weapon systems. The efficient use of energy in major systems will help assure that the DoD will

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IMPROVING ENERGY EFFICIENCY OF MAJOR WEAPON SYSTEMS

July 1982

Donna J.S. Peterson
Connelly D. Stevenson

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EXECUTIVE SUMMARY

The Defense Department's mobility fuel consumption is rising, and the cost of that consumption is rising even faster. From FY79 to FY81, consumption of mobility fuels increased by five percent, but the real cost of that consumption more than doubled, going from $2.8 billion to $6.2 billion in 1979 dollars. Fuel costs are growing more rapidly than other operating and support costs, thus consuming a growing fraction of operating and maintenance (O&M) funds.

Lack of attention to future fuel requirements of major weapon systems during their development levies a tax which will be paid well into the future. One solution to the problem of having to allocate an increasing fraction of the O&M account to fuel is to assure energy efficiency in weapon systems acquired.

Since not all systems consume large quantities of fuel, the Department of Defense (DoD) should concentrate on those that are energy intensive. Energy intensity depends on such factors as usage rate, consumption per unit of equipment, force structure, logistics support, and timing of acquisition of end items.

We have incorporated these factors into a method to designate developing systems as energy intensive early enough in the acquisition process to affect the system's energy efficiency. The method uses an energy consumption threshold specific to the warfare area of the system under consideration. Thus, all warfare communities are sensitized to the need to improve weapon system energy efficiency.

Energy efficiency of each system identified as energy intensive can best be promoted by monitoring and evaluating the energy portion of the system's life cycle cost (LCC). The evaluation should include an assessment of the sensitivity of the system's LCC to fuel price uncertainty. The effect of design maturation on system energy requirements should be reviewed at every acquisition decision milestone.

DoD is now planning weapon systems that will be fielded in the next century. Our recommendations will help DoD to control the energy consumed by major weapon systems in an environment of rising energy costs and possible energy shortages.

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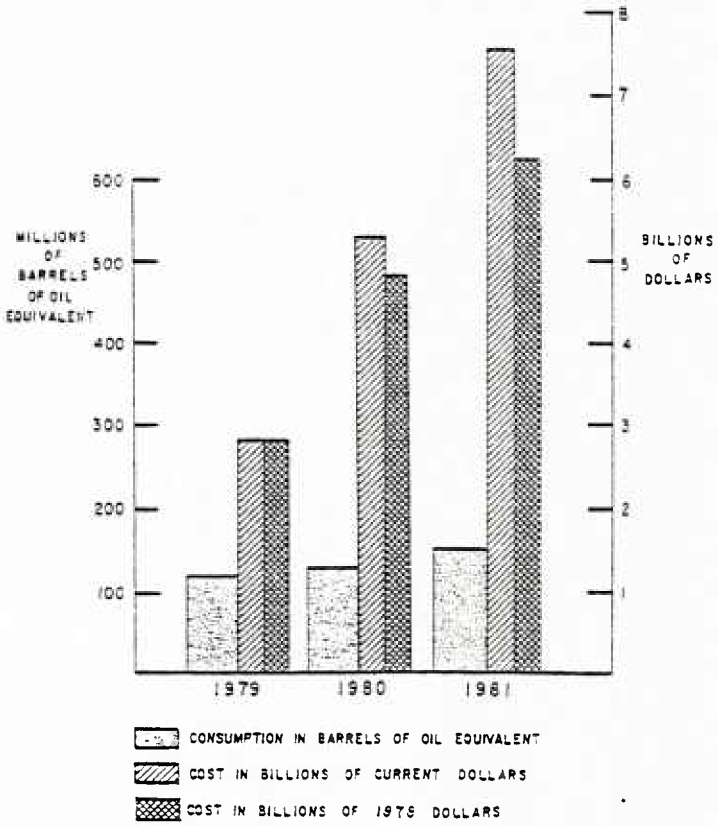
CHAPTER 1. INTRODUCTION

DEFINITION OF THE PROBLEM

Although the "energy crisis" seems to have been displaced by other global economic problems, it hasn't left the Department of Defense (DoD). DoD's energy bills are still climbing. Increases in both consumption and unit cost contributed to a DoD mobility energy bill that was 2.2 times higher, in real terms, in FY81 than it was in FY79, as shown in Figure 1-1. The effect

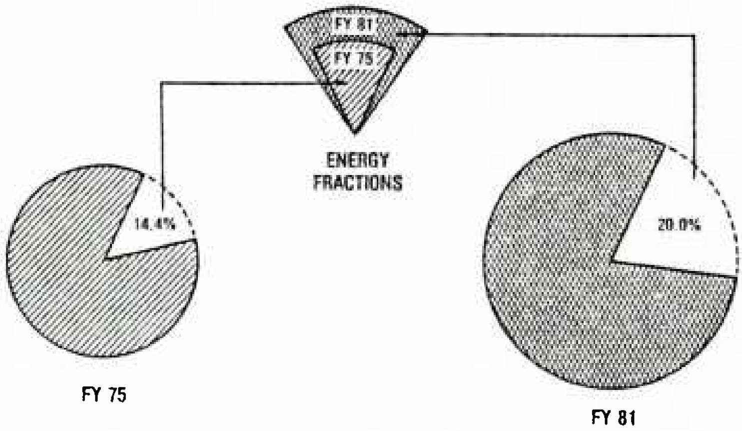
FIGURE 1-1. COST AND CONSUMPTION OF MOBILITY FUELS FOR DOD



SOURCE: DEFENSE ENERGY MANAGEMENT PLAN

is that mobility energy is taking a larger piece of a larger DoD Operations and Maintenance cost pie as shown in Figure 1-2.

FIGURE 1-2. ENERGY AS A FRACTION OF O&M OUTLAYS



Source: Defense Energy Management Plan

Mobility fuels account for 60 percent of the total energy consumed by DoD and 72 percent of the total cost of energy. Most mobility fuels are petroleum products,[1] and mobility requirements account for 88 percent of the petroleum consumed by the department.

The real cost of mobility fuels has risen dramatically in the last decade. The world's economy has now accommodated the new oil cost structure, however, and attention has shifted away from energy cost and supply. But the relief is not permanent. There is a consensus among forecasters that, in the long term, the real price of energy will rise substantially because of upward pressure on demand from a stronger global economy and the industrialization of

[1]Nuclear fuel consumed by nuclear powered naval ships is excluded from the Defense Energy Information System, from which the consumption statistics are derived. Small quantities of alcohol as gasohol and synthetic fuels are consumed but represent an insignificant portion of mobility consumption.

emerging nations. The possibility remains that political events, with little or no warning, will cause widespread shortages and price hikes. The joint effects of politics and economics give reason for concern in all consuming sectors, including the DoD. With the recent history of energy price volatility, the promise of long term real price increases, and the danger of short-term price and supply turbulence, we can expect that energy will be a driver of weapon system ownership costs.

The Commerce Department recently reported that the supply of liquid petroleum fuel for the transportation sector will suffer the greatest strain in the years ahead. To meet the limits that will exist on petroleum supply, current automobile mileage standards must double.[2] If automobile and truck fuel efficiency must increase by 100 percent to fit the future supply-demand outlook, the message for the DoD, whose major energy requirement is mobility fuels, becomes clear.

The prospect of a continuing upward trend for real energy prices makes more efficient use of fuels a necessity. In this context, using fuel efficiently does not mean conserving energy by using equipment less. Efficiency, for our purposes, is a concept of economy, meaning maximizing capability for a given budget or conversely, minimizing the cost of attaining a given capability. These two statements are equivalent because the weapon system that maximizes capability for a given cost is the same system that minimizes the cost of attaining that capability.[3] When considering energy alone, the goal is to maximize performance given a limited number of fuel dollars or to

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[2]U.S. Department of Commerce, "U.S. Energy for the Rest of the Century, 1982," July 2, 1982.

[3]This statement of efficiency closely follows a discussion by Charles J. Hitch in "Economic Analysis for the National Defense," printed in Price Theory in Action, Donald Watson, ed., Houghton Mifflin Co., 1965.

minimize the fuel budget given a desired level of performance, with all other factors held constant.

Enhancement of fuel efficiency in fielded systems, or in developing systems whose performance characteristics and propulsion subsystems have already been determined, is helpful but does not promise a final solution. Aerodynamic and engine modifications have improved the propulsion efficiency of several families of military jet aircraft, and such innovations as new hull cleaning techniques have facilitated more fuel-efficient ship operation, but these improvements are not significant enough to change the trends of increasing consumption and cost. Conservation measures like towing rather than taxiing aircraft are helpful, but the potential for changing the trends is also small. New systems, to be fielded late this century or early next century, present the most leverage for improving Defense energy efficiency. In order to influence the energy requirements of new systems, the DoD must examine them while their performance specifications and propulsion subsystem designs are still flexible enough to absorb meaningful fuel efficiency improvements.

SOLVING THE PROBLEM WITHIN THE FRAMEWORK OF THE MAJOR SYSTEM ACQUISITION PROCESS

DoD Directive (DoDD) 5000.1 sets the stage for improving the fuel efficiency of major weapon systems in the early part of the development process.[4] This principal acquisition policy directive specifies cost effectiveness and improved readiness and sustainability to be among the major acquisition management principles and objectives. It explicitly directs that "a cost-effective balance be achieved among acquisition costs, ownership costs and system effectiveness, in relation to the mission to be performed." On the

[4]Department of Defense, "Major System Acquisitions," DoD Directive 5000.1, March 29, 1982.

subject of affordability, the directive requires that resources specifically identified "to operate and support the deployed system effectively" be available or programmed before approval will be granted for the system to proceed into full-scale development or production.

The prominence of affordability, supportability and system readiness is maintained in the series of documents which implement DoDD 5000.1. Succeeding drafts of the forthcoming DoD Instruction 5000.2, "Major System Acquisition Procedures," and supplementary documents[5,6] affirm the importance of operational suitability[7] objectives. The DoD Component sponsoring the initiation of major system acquisition must include in its justification for major system new start (JMSNS) the "general magnitude of resources it is prepared to commit to acquire <u>and</u> <u>operate</u> a system to satisfy the need."[8] A life cycle cost (LCC) estimate must be prepared during the initial acquisition phase, concept exploration, for consideration at Milestone I and be updated for each succeeding Milestone. The importance of energy is now explicitly recognized by the establishment of a new system design consideration: "Energy. The major consideration shall be minimizing the cost of system energy use and the substitution of other energy sources for petroleum."[9]

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[5]Under Secretary of Defense Memorandum, "Major Defense System Acquisition Program Documentation Format," April 12, 1982.

[6]Department of Defense Instruction (DoDI) 5000.39 (DRAFT), "Acquisition and Management of Integrated Logistic Support for Systems and Equipment," July 23, 1982.

[7]Operational Suitability -- the degree to which a system can be placed satisfactorily in field use, with consideration being given to availability, compatibility, transportability, interoperability, reliability, wartime usage rates, maintability, safety, human factors, manpower supportability, logistic supportability, and training requirements. DoDD 5000.1, op. cit.

[8]Department of Defense, DoDI 5000.2 (DRAFT), "Major System Acquisition Procedures" April 9, 1982. (Underscore added.)

[9]DoDI 5000.2 (DRAFT) op. cit.

System energy costs are recognized as a pre-eminent ownership cost driver, and responsibility for their oversight is established, i.e., DoDD 5000.1 assigns to the Assistant Secretary of Defense (Manpower, Reserve Affairs, and Logistics) responsibility "for policy on ... energy ... planning for new systems throughout their life cycle" and to the Director, Program Analysis and Evaluation responsibility to "evaluate cost-effectiveness studies prepared in support of milestone decisions." Ownership cost considerations compete with operational effectiveness considerations and other operational suitability considerations at every decision point in the acquisition process. So, the framework for improvement exists (DoDD 5000.1), or nearly exists (DoDI 5000.2 DRAFT). But how should we work within that framework?

We want to concentrate analytical effort where the payoff is greatest for the resources that can be devoted to the job: those developing systems whose projected energy requirements are among the highest. Within DoD, aircraft systems are, unequivocally, the largest consumers of fuel. However, focusing on aircraft systems precludes other warfare areas from becoming sensitized to the need to improve energy efficiency. Our strategy is to pick those developing systems in each warfare area, (land, sea and air), with the highest projected energy consumption.

Energy costs are not a new element of system ownership costs. The new aspect is the growing share of operational costs now attributed to energy and the recognition that energy costs require a commensurate increase in attention. What is needed is an analysis that covers the anticipated life of the system, automatically produces consumption as well as cost figures, and allows study of the uncertainty of both types of estimate. Such an analysis would fit well into current procedures, taking the form of a more complete and exacting version of the energy portion of the life cycle cost analysis already required for the system.

The next three chapters pursue this approach. Chapter 2 presents a method for deciding whether a developing system is "energy intensive" and, if it is, for monitoring projections of its energy needs as it continues through the acquisition process. Chapter 3 summarizes life cycle cost evaluation methodology, with emphasis on the uncertainty of future energy cost. Chapter 4 illustrates application of the method, through a case study. A final chapter then summarizes the arguments for increased attention to energy consumption and cost and the recommendations for achieving that attention in an effective way.

CHAPTER 2. DESIGNATING A SYSTEM ENERGY INTENSIVE

BACKGROUND

We use the term "energy intensive" to designate systems that consume relatively large amounts of fuel regardless of their specific fuel efficiency. A jet engine may be fuel efficient but the aircraft family which it propels will be energy intensive if it accounts for a substantial part of the fuel budget.

If we are to apply closer scrutiny to the energy portion of the LCC of new systems, the principles of economic efficiency are best served by giving priority to those systems whose projected energy use is highest. We propose segregation of systems according to their warfare area and designating those systems within each area that consume relatively large amounts of fuel as energy intensive. This way, specialists in all warfare areas will simultaneously become aware of the importance of energy and the benefits to be gained from increasing energy efficiency.

FACTORS AFFECTING ENERGY INTENSITY

Energy intensity has been identified with absolute levels of fuel consumption and the relationship of fuel consumption of a particular system to the consumption of all systems in the same warfare category. When we refer to weapon system consumption, we mean the consumption of the total system, including logistic support, over the system's life cycle.

The factors which influence life cycle fuel consumption are:

- consumption per measure of time per end item (e.g., gallons per hour per aircraft, Btu's per hour per boiler);
- force structure (maximum number of end items, squadrons);
- item usage rate (hours in operation per year or distance traveled per year);

- logistics support requirements (includes new storage facilities, new support equipment, and additional war reserves among others); and

- timing of acquisition of end items.

The first three factors, consumption rate, force structure and usage rate, can be used to compute yearly fuel consumption at maximum force level for peacetime and wartime scenarios. The fourth, support cost, is an add-on element to cover new fuel-related equipment, facilities, transportation systems and war reserves which will be needed to support the proposed system. Finally, a schedule for acquisition of the end items is required.

IDENTIFYING ENERGY INTENSIVE SYSTEMS

In order to maximize energy efficiency, new systems should be tested for energy intensity by Milestone I to initiate their energy requirements scrutiny as early in the development process as possible. Several factors which influence a system's fuel requirements have been identified above. We suggest that a worksheet such as Table 2-1 be used by the energy directorates of OSD and the Services to collect and organize these energy data. All data are (or should be) obtainable from existing or new sources such as the Milestone I System Concept Paper and its accompanying Cost Effectiveness Analysis. (The Independent Cost Analysis, the Logistics Annexes to the Milestone II and III Decision Coordinating Papers, and the Extended Planning Annex of the Five Year Defense Plan will provide data for subsequent updating of the worksheet to monitor the effects of later phases of system development on energy requirements.)

The data entered in Table 2-1 show system fuel requirements by year. Using a projection of future fuel prices, one can calculate the cost of fuel over the life of the proposed system. The fuel cost data are part of the life cycle cost of the system and can be used in the sensitivity analysis described in Chapter 3. The worksheet has space for an estimate of the additional cost of logistics fuel support specific to the system. This alerts the preparer to the fact that the fuel support equipment may be an important part of the energy requirements.

TABLE 2-1. ENERGY REQUIREMENTS WORKSHEET

Program Name: ____________
System Life: ____________
Fuel Type (Primary): ____________
Fuel Type (Alternative): ____________
Item Fuel Consumption (fuel volume/hours or miles/item): ____________________________________

Consumption	Life Cycle (years)									
	____	____	____	____	____	____	____	____	____	____
Number of Items Acquired, Modified or Disposed of	____	____	____	____	____	____	____	____	____	____
Cumulative Number of Items in Inventory	____	____	____	____	____	____	____	____	____	____
Item Usage Rate (hours or miles per year)	____	____	____	____	____	____	____	____	____	____
Annual Consumption[1]	____	____	____	____	____	____	____	____	____	____
Change in Peacetime Operating Stock (BBLS)	____	____	____	____	____	____	____	____	____	____
Change in War Reserves (BBLS)	____	____	____	____	____	____	____	____	____	____
Total Annual Fuel Requirement[2]	____	____	____	____	____	____	____	____	____	____

Fuel Logistics Support

Additional Fuel Storage Capacity ($): ____________

Fuel Handling Equipment ($): ____________

Other: ____________

[1]For each year, Item Fuel Consumption x Cumulative Number in Inventory x Item Usage Rate.

[2]Annual Consumption + Change in Peacetime Operating Stock + Change in War Reserves.

In many cases, it will be obvious whether or not a system is energy intensive, because of either the fuel requirements or large expenditures for support equipment. (Most fixed-wing aircraft, tanks and ships will be energy intensive while most missiles and helicopters will not.) In the few instances when it is not obvious that a system is energy intensive, we recommend the use of an annual fuel consumption threshold specific to the warfare area to decide whether the system requires more detailed of the energy analysis. The thresholds displayed in Table 2-2 are based on the proportion of mobility fuels consumed by the three functional warfare areas: aircraft operations, ship operations, and ground operations. The threshold criteria are based on FY75 baseline mobility consumption and represent 1 percent of consumption in each functional area, rounded to convenient numbers. FY75 mobility consumption was chosen because the DoD energy goals are all tied to FY75 consumption as the baseline. One percent represents a convenient level of consumption of aircraft, ship and ground system families which separates higher from lower energy consuming systems. If the annual consumption of the fully operational system exceeds the warfare area consumption threshold, it is designated energy intensive.

TABLE 2-2. FUEL CONSUMPTION THRESHOLDS FOR DESIGNATING SYSTEMS ENERGY INTENSIVE

Warfare Area	Annual Fuel Consumption in Barrels of Oil Equivalent
Air Warfare Systems	1,000,000
Sea Warfare Systems	300,000
Land Warfare Systems	150,000

In summary, the Energy Requirements Worksheet (Table 2-1) will help identify systems that are expected to consume large quantities of fuel or require costly fuel-related logistics support. For those cases where energy intensity is not obvious, a comparison to the fuel consumption thresholds (Table 2-2) will aid the decision-maker. After the worksheet is used to make the initial decision whether a system is energy intensive, it should be used as an accounting tool to monitor changes in system energy data throughout the acquisition process.

CHAPTER 3. EVALUATING AN ENERGY INTENSIVE SYSTEM

METHODS OF EVALUATING COSTS

We have argued that a system which has been designated energy intensive merits special attention and additional analytic effort. The evaluation method should adhere to our overall criteria of efficiency, or getting the most for the least effort. The remainder of this chapter outlines a method of testing the effect of energy price changes on system decisions.

We examined several analytical methods (described in Appendix B) for use as an evaluation technique. We recommend the use of life cycle costing since this method is both simple and familiar. Additionally, all other methods require an estimate of cash flows over the life cycle, that is, a life cycle cost estimate, as an initial step.

Life cycle cost is the sum of all costs required to develop, procure, operate and retire a system. A useful life cycle cost analysis has certain qualities. First, all categories of cost should be identified and included in the analysis. Second, the factors which have been identified as relevant should be measurable. Some factors may be measured fairly objectively: the cost of an "off the shelf" engine. Other factors may be measured only subjectively: how much schedule should be traded for an increase in performance. Cost and schedule, although difficult to know with certainty, are amenable to measurement. Performance or the capability of the system is probably the most difficult to measure. However, depending upon the specific system mission, there are many measures of performance which are currently used, such as the number of targets hit, the exchange ratio or the number of sorties flown. Last, to make comparisons among systems, they should be compared on an equivalent basis. Since systems hardly ever have equal capability, it is necessary to make adjustments in the life cycle cost analysis to facilitate the comparison. In many cases, it may be reasonable to use the performance measures specific to the systems to normalize costs to equivalent capability.

There is one additional point that needs clarification. Life cycle costing manuals published by the federal government often do not clearly distinguish between discounting and the treatment of inflation. Cash flows for government analyses are usually expressed in real dollars, sometimes called constant dollars, which are dollars adjusted to a fixed price level (for example, 1981 dollars or 1974 dollars). Occasionally, analyses are done in nominal dollars, sometimes called then-year dollars, inflated dollars, or current dollars, which include the estimated effect of inflation over time. To convert a cost stream of nominal dollars into real dollars, it is necessary to "deflate" the nominal dollars by some price index such as the Consumer Price Index or the GNP deflator. Conversely, price indices can be used to "inflate" real dollars into nominal dollars. Even if an analysis is carried out in real dollars, suppressing the effect of inflation, adjustments must be made for inflation since not all goods and services will rise at the same rate. This deviation from the general rate of inflation is often referred to as a "differential escalation rate." For example, if energy prices are expected to inflate 2 percent faster than other prices, the differential escalation rate for energy is 2 percent.

Discounting is an entirely different concept from inflating or deflating dollars. Individuals tend to prefer current consumption over future consumption because of uncertainty about the future. Discounting future cash flows is the analytical mechanism which is used to express this preference. The process of discounting takes into account the opportunity cost and the time value of resources. The opportunity cost of a project is measured by the value of the best alternative that must be foregone when the original project is undertaken. Appropriate discounting means that resources will be allocated to the highest valued use. Time value refers to the idea that the same resources consumed today are worth more than if they were to be consumed in the future because of the uncertain nature of the future. Individuals may choose to postpone current consumption in order to earn a return on their resources and be able to consume more in the future. Thus time value can be expressed as a real rate of return, or as a real rate of interest for financial instruments. For government projects, economists often associate time value with assuring a supply of resources for future generations. Discounting is used to systematically reduce the value of future resources (valued in dollars) to take into account the fact that current consumption is preferred. The discount rate implies how much more society would prefer to consume resources now than in the future: the higher the discount rate, the more society prefers current as opposed to future consumption. If real dollars are used in an analysis, the cash flows must be discounted by a real discount rate. If the analysis is done in nominal dollars then the nominal discount rate, which includes inflation, must be used.

OMB Circular A-94 requires the use of real dollars and a 7 percent real discount rate for government projects. Theoretically, it does not matter whether analyses are performed with real dollars or nominal dollars. As long as the analyses are internally consistent (all cash flows in real dollars or all cash flows in nominal dollars) and the appropriate discount rate is applied, then the decisions based on the analyses will be the same.

SENSITIVITY ANALYSIS FOR FUEL PRICE UNCERTAINTY

The previous section stated that the cost elements and relevant factors for life cycle costs must be measurable. In fact, all measures contain some amount of uncertainty. In this section, we present a way of dealing with uncertainty, using fuel prices as the focus.

Fuel price forecasts for government life cycle cost estimates have been too low since 1973. This means that projects which would have produced large savings at current fuel prices were rejected in the past because fuel was not expected to cost as much as it now does. Conversely, projects accepted on the basis of low or moderate future fuel price projections are much more expensive than expected.

Sensitivity analysis is a method of assessing uncertainty based on examining a range of possible outcomes. Its use is recommended in DoDI 7041.3, "Economic Analysis and Program Evaluation for Resource Management." In the general guidelines, the section on risk assessment states,

> "The analysis should include a test of the sensitivity of the results of any factor, including possible side effects, which may significantly impact on the problem under study."

The designation of a system as energy intensive indicates that fuel prices "may significantly impact" the system.

Sensitivity analysis involves analyzing the effects of differing assumptions for relevant factors. Relevant is the key word. The Air Force cost analysis of the KC-135 reengine program, cited earlier and discussed in Chapter 4, includes a sensitivity analysis on fuel consumption rates, not prices. In this case, fuel price is the relevant factor. We suggest that the official price escalations be used as the midpoint for the sensitivity analysis. There are no magic numbers, but we believe that the analysis should be performed with price escalations plus and minus 10 percent compared to the official rate. Specifically, if the Comptroller publishes a differential escalation rate for fuel of 2 percent, the analysis would be performed three times, with fuel escalating at annual rates of +2 percent, +12 percent and -8 percent. This recommendation assumes that the plus and minus 10 percent is set high enough to be a reasonable boundary on the possible outcomes.

The results of a sensitivity analysis are used to assess the effects of energy cost uncertainty on decisions. Some projects will show little impact as prices increase at a faster rate. Those projects which are sensitive to fuel prices may change radically. Projects which are uneconomical at very low price escalations may be shown to be economical when fuel prices are increasing rapidly. The converse may also be true.

A project which is sensitive to fuel price growth rates is more risky due to the uncertainty of future prices. Identifying the riskiness helps the program manager deal with it. In addition, sensitivity analysis will help the decision-maker identify conservation-oriented trade-offs which become economical when fuel prices grow at a rate that is more rapid than expected.

SUMMARY

The foregoing discussion highlighted life cycle costing and the use of sensitivity analysis to examine the effect of uncertainty. As long as weapon systems are compared on the basis of equivalent capability, the system or option with the lowest life cycle cost is the one that should be pursued. For assessing the impact of energy costs, the need is not so much for a new methodology, but rather a better execution of current methods. This would require a more careful identification of relevant energy factors, such as the support tail, and a more careful analysis of the costs and benefits of each option.

The measurement of future fuel prices has been a particular problem. Sensitivity analysis is a simple technique and permits an assessment of the impact of uncertainty and risk. In the next chapter we present a sensitivity analysis using cost data for the KC-135 Reengine Program.

CHAPTER 4. CASE STUDY OF AN ENERGY INTENSIVE SYSTEM

THE KC-135 REENGINE PROGRAM

The Boeing KC-135 has been the mainstay of the U.S. Air Force tanker fleet for over twenty years. Since the first tanker squadron was formed, the number of air refuelable aircraft in the operational inventory has increased tremendously. It now includes not only bombers but also attack, cargo, electronic warfare, fighter, and reconaissance aircraft. The heavy demands being placed on the KC-135 have forced the Air Force to look for a replacement aircraft or to extend the life of and acquire additional KC-135's.

There are two parts to the tanker problem. The amount of fuel to be off-loaded has increased, and the number of airborne refuelings required has increased. The purchase of the larger KC-10 tanker would solve part of the problem since each KC-10 is able to supply larger amounts of fuel than a KC-135. However, each KC-10 can serve only a limited number of aircraft in a period of time and therefore does not solve the problem of the increasing number of individual aircraft demanding aerial refueling. In an effort to accommodate the increasing number of aircraft, it has been proposed that the KC-135 be modified to extend its service life and increase its capability. The modification examined in this case study is the replacement of the current J57 engine with the more powerful, more fuel efficient CFM56.

The reengining of the aircraft is to be done concurrently with other modernization efforts, e.g., wing reskin program, which are expected to extend the life of the aircraft well into the twenty-first century. The Air Force is reengining these aircraft for many reasons; perhaps the most important reason is increased capability. The Independent Cost Analysis (ICA) prepared by the

Air Force, states that the offload capability of 300 reengined KC-135's will equal that of 435 of the aircraft with the old engines. Additional reasons for reengining include fuel savings of 25 percent for comparable missions and a reduction in noise and air pollution.

Although, there are many benefits to be gained from the reengining, this case study focuses on the benefits accruing from the fuel savings. The purpose of the case study is to demonstrate the methodology of sensitivity analysis as applied to an existing Service project. All cost data are taken from the ICA prepared by the Air Force in May 1981. However, the case study illustrates sensitivity analysis and is not intended to represent Air Force life cycle cost estimates or to critique the Air Force decision.

CASE STUDY ASSUMPTIONS

The ICA document presents detailed breakdowns of cost categories such as development, production, spares and O&S. The document does not present a figure for total life cycle cost. The Air Force ICA lists the following assumptions.

- All costs are in constant 1981 dollars.
- The price of JP4 is constant at $1.168/gal.
- The peactime flying rate for a KC-135 is 410 hours per year.
- A KC-135 squadron consists of 19 aircraft.

LMI aggregated costs for the broad categories in order to construct life cycle cost streams on which sensitivity analysis might be performed. We made the following additional assumptions for the sensitivity analysis.

- The real discount rate is 7%.
- The analysis covers 20 years.
- The J57 rehabilitation, which would be undertaken in lieu of reengining, would increase fuel efficiency by 5%.

- The J57 rehabilitation would take place in four years with 25 percent of the engines rehabilitated each year.

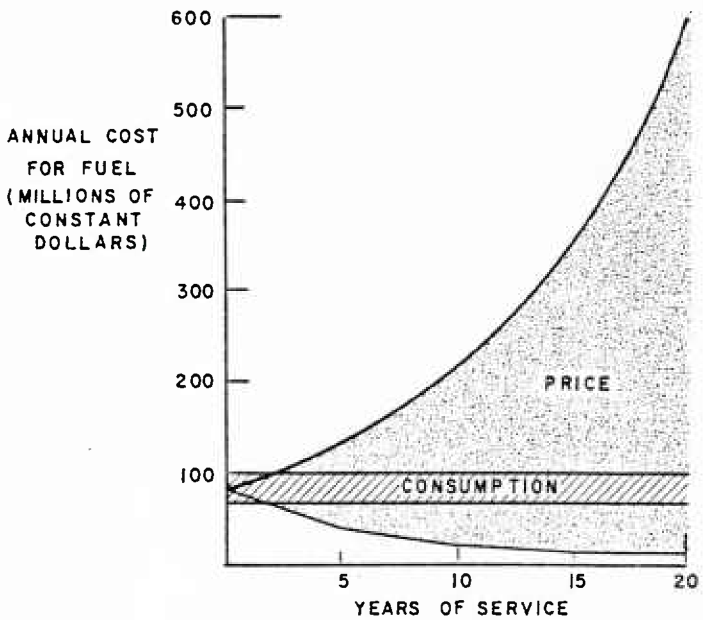
- The O&S savings were computed yearly on the assumption that squadrons of 19 aircraft each were formed before additional reengined aircraft were assigned to a new squadron.

Before proceeding, there are three aspects of the data which need to be noted. First, the ICA presents the option of reengining 99, 299 or all 641 aircraft. Our sensitivity analysis is performed on the option to reengine 299 aircraft.

Second, the ICA does not mention any salvage value for the J57 engines which are being removed. It seems unrealistic that the old engines would have no value.

Last, there was a fuel consumption sensitivity analysis in the ICA, but not a fuel price sensitivity analysis. Figure 4-1 illustrates why a fuel cost sensitivity analysis is more important than a fuel consumption sensitivity analysis. The figure is based on a hypothetical aircraft (not the KC-135) that consumes 1,000 gallons of fuel per hour, flies 300 hours per year, and

FIGURE 4-1 CONSUMPTION SENSITIVITY ANALYSIS AND COST SENSITIVITY ANALYSIS



has a service life of 20 years. There are 300 aircraft in the inventory and the current price of fuel is set at $1 per gallon. The analysis is presented in terms of the dollars it would cost to buy the fuel each year.

The lined segment represents the boundaries of the cost of fuel when consumption changes plus and minus 10 percent. The shaded portions represent the boundaries of the fuel cost with fuel prices increasing or decreasing at an annual rate of 10 percent. Table 4-1 summarizes the information in Figure 4-1.

TABLE 4-1. SENSITIVITY ANALYSES FROM FIGURE 4-1
(Billions of Constant Dollars)

Consumption Sensitivity	Total Cost Over Service life
Base Case + 10%	$ 1.9
Base Case	1.8
Base Case - 10%	1.6
Price Sensitivity	
Base Case + 10% annually	$ 5.2
Base Case	1.8
Base Case - 10% annually	0.7

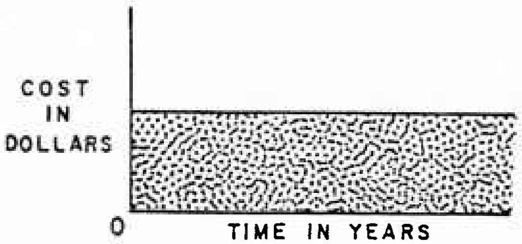
Because prices in the example compound annually, the area of uncertainty for price (the shaded portion) is much larger than the area of uncertainty for consumption (lined area). For the change in consumption, the range in total fuel cost is $0.2 billion while the range derived with fuel price escalation is $4.5 billion. It is also noteworthy that the penalty for underestimating price increases is much larger (top shaded portion) than either the penalty for incorrectly estimating consumption (lined portion) or the penalty due to overestimating price decreases (bottom shaded portion).

METHOD

In this case study, the sensitivity analysis is conducted within the framework of a life cycle cost analysis. The KC-135 reengine program is a modification of an existing system, so the life cycle cost discussed is the life cycle cost of the modification program, not of the system. With our concentration on the fuel savings generated by the reengining, the analysis is akin to an investment analysis with dollars invested to create a future savings. A simplified example of a hypothetical system will clarify the distinction.

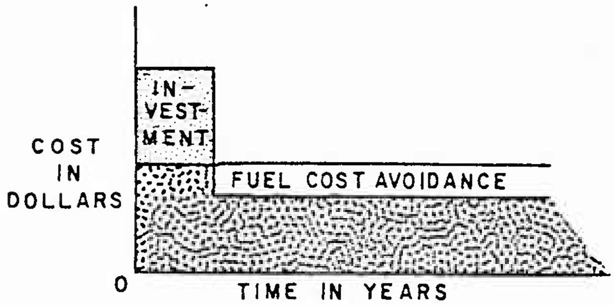
Figure 4-2 shows the life cycle cost of an existing system. The system has been operational for some time so the initial acquisition costs are sunk and do not appear. The operating costs are the same each year, so the remaining life cycle cost of the system is the area under the horizontal line.

FIGURE 4-2 LIFE CYCLE COST OF A HYPOTHETICAL SYSTEM



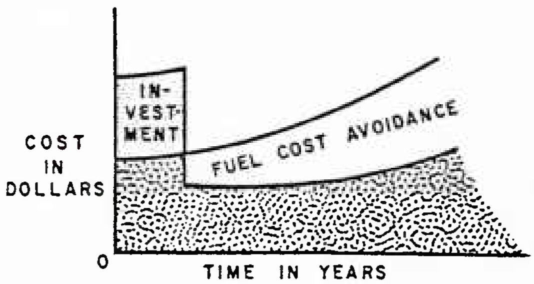
A modification of the system which requires an investment in new equipment is proposed to save energy (Figure 4-3). The life cycle cost of the system is the shaded area plus the area labeled investment. To determine the life cycle cost of the modification program only, the area labeled "investment" is compared to the area labeled "fuel cost avoidance". If the investment area is larger than the cost avoidance area, the life cycle cost is positive as the fuel savings do not cover the investment. If the cost avoidance area is larger, the life cycle cost is negative because the cost avoidance has covered the investment cost.

FIGURE 4-3 LIFE CYCLE COST OF MODIFIED SYSTEM



Sensitivity analysis examines the effect on life cycle costs of the modification as the size of the cost avoidance box changes due to fuel price changes. Figure 4-4 shows the change in fuel cost avoidance when fuel prices rise over time and the investment cost remains the same. Since the life cycle cost of the modification program is the investment cost minus the cost avoidance, the life cycle cost declines as the cost avoidance increases since more and more of the investment is covered by the cost avoidance.

FIGURE 4-4 LIFE CYCLE COST OF MODIFIED SYSTEM WITH INCREASING FUEL PRICES



Returning to the KC-135 reengining program, a modification program, the life cycle costs presented are the costs of reengining: the investment costs to develop, procure and install the engines and the cost avoidance due to the fuel savings and a reduction in required maintenance. The sensitivity analysis was performed on a cost estimate derived from the ICA cost data.

Appendix A presents life cycle cost and sensitivity analysis data in tables A-1 through A-5. Table A-1[1] is the life cycle cost estimate for the modification using the cost categories presented in the ICA. Table A-2 adds the cost of rehabilitating the old engines, which will have to be done if the KC-135 is not reengined. The estimated cost is $852 million and it enters the life cycle cost estimate of the modification as a cost avoidance because it is money that will not have to be spent if the aircraft are reengined. It was assumed that rehabilitating the old J57 engines would increase engine efficiency and therefore reduce fuel consumption somewhat. We assumed a 5 percent reduction in fuel consumption from the rehabilitation and adjusted the fuel cost avoidance to account for this.

Table A-3 is constructed by discounting all the cash flows in the second table by the OMB-prescribed 7 percent. The sensitivity analysis was performed on the life cycle cost estimate which contains the savings from the rehabilitation and is discounted at 7 percent.

Tables A-4 and A-5 present the sensitivity analysis performed on the data in Table A-3. Table A-4 shows the effect of a 10 percent annual increase in fuel prices and Table A-5, the effect of a 10 percent annual decline in fuel prices.

RESULTS

The summary of life cycle cost estimates (Table 4-2) indicate that the investment cost of the modification is not covered by the fuel savings in any case; life cycle cost for the modification program is always positive.

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[1] The convention in the tables is to enter investment costs as positive quantities and cost avoidances as negative quantities. Life cycle cost is the sum of all entries in a table.

TABLE 4-2. LIFE CYCLE COST ESTIMATES FOR KC-135 REENGINE PROGRAM

(Millions of 1981 Dollars)

	ICA Data	ICA Data With Rehabilitation Cost	ICA Data With Rehabilitation Cost And Discounting
Investment Cost	4,880	4,880	3,877
Less Maintenance Cost Avoidance	550	550	242
Less Fuel Cost Avoidance	899	695	305
Less Rehabilitation Cost Avoidance		852	615
TOTAL LIFE CYCLE COST OF MODIFICATION	3,431	2,783	2,715

Table 4-3 shows the fuel price sensitivity analysis performed on the ICA data including the rehabilitation cost savings and with all cash flows discounted at 7 percent. As the price of fuel escalates, the fuel cost avoidance increases. The life cycle cost of the modification program decreases because more of the investment cost is covered by the fuel cost avoidance.

TABLE 4-3. FUEL COST SENSITIVITY ANALYSIS ON KC-135 REENGINE PROGRAM

Includes Rehabilitation and Discounting

(Millions of 1981 Dollars)

	Fuel Prices Decline 10% Per Year (Table A-5)	Fuel Prices Constant (Table A-3)	Fuel Prices Increase at 10% Per Year (Table A-4)
Investment Cost	3,877	3,877	3,877
Less Maintenance Cost Avoidance	242	242	242
Less Fuel Cost Avoidance	119	305	990
Less Rehabilitation Cost Avoidance	615	615	615
TOTAL LIFE CYCLE COST OF MODIFICATION	2,900	2,715	2,029

CHAPTER 5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

DoD's mobility fuel consumption is rising, and the cost of that consumption is rising even faster. The uncertainty of future fuel availability and price makes it difficult to estimate the cost of supporting the major weapon systems to be fielded in the period beyond 1990. If the real cost of petroleum fuels drops over the next few decades and we face a twenty-first century in which energy costs do not exert as much economic influence as they have in the last decade, then there is no need for the DoD to pay explicit attention to the fuel fraction of the operational costs of future weapon systems. However, the real cost of oil is virtually certain to increase. Additionally, it is likely that episodic shortages and accompanying price shocks due to global political instability will recur. We think that the DoD should take positive steps toward controlling the consumption and cost of energy of future weapons systems.

Recognition of the importance of energy as an O&S cost is growing. However, not every new system is energy intensive. Not every one requires special attention with respect to energy. This report lays out a procedure for identifying those systems whose energy requirements make them high leverage contributors to improvements in DoD energy efficiency. We recommend that new systems be tested for energy intensity and that data on their energy consumption be assembled and updated prior to each acquisition milestone, so that the effect of the maturation of the system design on fuel requirements can be monitored.

We recommend that the contribution of energy to the cost of supporting major systems be evaluated by more exhaustive examination of system energy requirements in the life cycle cost analysis process. Once the life cycle cost of a program is estimated, we recommend that the sensitivity of the estimates with respect to fuel price changes be tested. Our case study shows how the sensitivity analysis might be done and how it fits into the life cycle costing format.

The "energy crisis" may have disappeared but the problem of increasing energy costs remains. DoD must plan now for the energy needs of systems which will be fielded in the next century. We recommend that the Assistant Secretary of Defense (Manpower, Reserve Affairs and Logistics) (ASD(MRA&L)) take the following positive steps toward controlling the consumption and cost of future systems.

- Request that the Assistant Secretaries of the Army (Research, Development and Acquisition), the Navy (Research, Engineering and Systems), the Navy (Shipbuilding and Logistics), and the Air Force (Research, Development and Logistics) test all new major systems for energy intensity as part of the preparation for Defense Systems Acquisition Review Council (DSARC) Milestone I.

- Instruct the Director, Defense Energy Policy, to monitor new systems which have been designated energy intensive, to assess the evaluation of the system's energy requirements and to keep the appropriate DSARC officials informed.

- Inform the Director, Program Analysis and Evaluation of new systems designated energy intensive, and request his assistance in improving the analysis of energy's contribution to LCC and the sensitivity of LCC to changes in energy cost as well as consumption.

In summary, we believe that mobility energy cost growth must be controlled, and that steps can and should be built into the framework of the major system acquisition process to achieve that goal.

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APPENDIX A

KC-135 REENGINE PROGRAM DATA

Tables A-1 through A-5 present life cycle costs and the sensitivity analyses. The ICA[1] divided costs into seven major categories as follows.

1. Development - contains costs such as preliminary engineering, trade studies on the design, flight test manuals, among others.

2. Production - contains cost of manufacturing and installing the engine modification kits, material costs, labor costs, support equipment and training.

3. Initial Spares - estimates cost of acquiring initial level of spares.

4. Interim Contractor Support - cost estimate for depot level maintenance support for three years beginning with delivery of first engine.

5. Replenishment Spares - estimates cost of obtaining additional spares above the initial requirement.

6. Retrofit - includes production labor and material plus installation since the main landing gear and the engine "quick start" are to be retrofit after flight test.

7. Operating and Supports - contains estimates of recurring costs for manpower, maintenance and fuel.

Since the cost of initial spares and contractor support is small, these categories are included within the production category in the appendix tables. Fuel costs are broken out separately since they are the object of the analysis. In the table, cost avoidances are presented as negative quantities, thus, the life cycle cost reported at the bottom is the net figure of total cost less cost avoidance.

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[1] U.S. Air Force, "KC-135 Reengine Modification Independent Cost Analysis", May 1981.

TABLE A-1. LIFE CYCLE COST OF KC-135 REENGINE PROGRAM - ICA DATA

(Millions of 1981 Dollars)

	Year										
Cost Category	81	82	83	84	85	86	87	88	89	90	91-2000
Development	75.3	66.7	36.8	3.5							
Production	8.0	274.8	1031.7	956.4	954.2	920.8	332.1	41.0	17.1		
Replenishment Spares				0.6	5.6	8.2	8.1	1.9			
Retrofit				31.6	26.2	29.3	21.2	29.3	1.1		
O&S Savings (W/O Fuel)				- 1.5	- 10.3	- 18.7	- 27.2	-36.4	-38.0	-38.0	-38/yr.
Fuel Savings				- 2.5	- 16.8	- 31.2	- 44.8	-60.0	-62.0	-62.0	-62/yr.
TOTAL	83.3	341.5	1068.5	988.1	958.9	908.4	289.4	-23.3	-81.8	-100.0	-1000.0

TOTAL LIFE CYCLE COST $3.4 billion

TABLE A-2. LIFE CYCLE COST OF KC-135 REENGINE PROGRAM - ICA DATA WITH REHABILITATION COST

(Millions of 1981 Dollars)

Cost Category	Year 81	82	83	84	85	86	87	88	89	90	91-2000
Development	75.3	66.7	36.8	3.5							
Production	8.0	274.8	1031.7	956.4	954.2	920.8	332.1	41.9	17.1		
Replenishment Spares				0.6	5.6	8.2	8.1	1.9			
Retrofit				31.6	26.2	29.3	21.2	29.3	1.1		
O&S Savings (W/O Fuel)				- 1.5	- 10.3	- 18.7	- 27.2	-36.4	-38.0	-38.0	-38/yr.
Fuel Savings				- 1.9	- 13.0	- 23.6	- 34.4	-46.0	-48.1	-48.1	-48.1/yr.
J57 Rehab.				-208.0	-208.0	-208.0	-208.0				
TOTAL	83.3	341.5	1068.5	780.7	754.7	708.0	91.8	- 9.3	-67.9	-86.1	-861.0

TOTAL LIFE CYCLE COST $2.8 billion

TABLE A-3. LIFE CYCLE COST OF KC-135 REENGINE PROGRAM - ICA DATA WITH REHABILITATION COST AND DISCOUNTED AT 7% ANNUAL RATE

(Millions of 1981 Dollars)

Cost Category	Year 81	82	83	84	85	86	87	88	89	90	91-2000
Development	75.3	66.7	36.8	3.5							
Production	8.0	274.8	1031.7	956.4	954.2	920.8	332.1	41.9	17.1		
Replenishment Spares				0.6	5.6	8.2	8.1	1.9			
Retrofit				31.6	26.2	29.3	21.2	29.3	1.1		
O&S Savings (W/O Fuel)				- 1.5	- 10.3	- 18.7	- 27.2	-36.4	-38.0	- 38.0	-38/yr.
Fuel Savings				- 1.9	- 13.0	- 23.6	- 34.4	-46.0	-48.1	-48.1	-48.1/yr
J57 Rehab.				-208.0	-208.0	-208.0	-208.0				
Total	83.3	341.5	1068.5	780.7	754.7	708.0	91.8	- 9.3	-67.9	-86.1	-861.0
Present Value Factor	1.000	.935	.873	.816	.763	.713	.666	.623	.582	.544	--
Discounted Total	83.3	319.3	932.8	637.1	575.8	504.8	61.1	- 5.8	-39.5	-46.8	-307.4

TOTAL LIFE CYCLE COST $2.7 billion

TABLE A-4. SENSITIVITY ANALYSIS OF KC-135 REENGINE PROGRAM WITH REHABILITATION COST, DISCOUNTED AT 7% AND FUEL PRICES INCREASING AT 10% PER YEAR

(Millions of 1981 Dollars)

	Year										
Cost Category	81	82	83	84	85	86	87	88	89	90	91-2000
Development	75.3	66.7	36.8	3.5							
Production	8.0	274.8	1031.7	956.4	954.2	920.8	332.1	41.9	17.1		
Replenishment Spares				0.6	5.6	8.2	8.1	1.9			
Retrofit				31.6	26.2	29.3	21.2	29.3	1.1		
O&S Savings (W/O Fuel)				- 1.5	- 10.3	- 18.7	- 27.2	-36.4	-38.0	- 38.0	-38/yr.
Fuel Savings				- 2.5	- 19.0	-38.0	- 60.9	-89.6	-103.1	-113.4	-1987.9
J57 Rehab.				-208.0	-208.0	-208.0	-208.0				
Total	83.3	341.5	1068.5	780.1	748.7	693.6	65.3	-52.9	-122.9	-151.4	-2367.9
Present Value Factor	1.000	.935	.873	.816	.763	.713	.666	.623	.582	.544	--
Discounted Total	83.3	319.3	932.8	636.6	571.3	494.5	43.5	-33.0	-71.5	-82.4	-865.8

TOTAL LIFE CYCLE COST $2.0 billion

TABLE A-5. SENSITIVITY ANALYSIS OF KC-135 REENGINE PROGRAM WITH REHABILITATION COST, DISCOUNTED AT 7% AND FUEL PRICES DECLINING AT 10% PER YEAR

(Millions of 1981 Dollars)

	Year										
Cost Category	81	82	83	84	85	86	87	88	89	90	91-2000
Development	75.3	66.7	36.8	3.5							
Production	8.0	274.8	1031.7	956.4	954.2	920.8	332.1	41.9	17.1		
Replenishment Spares				0.6	5.6	8.2	8.1	1.9			
Retrofit				31.6	26.2	29.3	21.2	29.3	1.1		
O&S Savings (W/O Fuel)				- 1.5	- 10.3	- 18.7	- 27.2	-36.4	-38.0	-38.0	-38/yr.
Fuel Savings				- 1.4	- 8.5	- 13.9	- 18.3	-22.0	-20.7	-18.7	-109.2
J57 Rehab.				-208.0	-208.0	-208.0	-208.0				
Total	83.3	341.5	1068.5	781.2	759.2	717.7	107.9	14.7	-40.5	-56.7	-489.2
Present Value Factor	1.000	.935	.873	.816	.763	.713	.666	.623	.582	.544	--
Discounted Total	83.3	319.3	932.8	637.5	579.3	511.7	71.9	9.2	-23.6	-30.8	-189.3

TOTAL LIFE CYCLE COST $2.9 billion

APPENDIX B. EVALUATION METHODOLOGIES

BACKGROUND

There are several analytical techniques for evaluating potential trade-offs among cash flows of a project or investment. The nature of the problem is to evaluate, year-by-year, the cash flows which will occur over the life of a project. To a private sector business, the cash outflows are the costs of acquiring equipment, leases and raw materials and the cost of operating and maintaining the system. The cash inflows are the dollars earned from sales of a product or service and the salvage value of any equipment. Although government projects do not generate sales and produce earnings, they do produce cash outflows for investments and operating costs and may generate cash inflows from salvage or cost savings. Therefore, government projects can be analyzed using common financial techniques.

The manager should have a method which allows him to evaluate projects in equivalent units so he can make comparisons among project alternatives. Also, if the budget is limited, the decision-maker wants to be able to use the evaluation method to determine the most efficient set of projects.

The most common methods used are:

- life cycle cost
- payback
- net present value of savings
- benefit to cost ratios
- internal rate of return
- linear optimization.

Discounted or undiscounted cash flows may be used in most of the methods. The net present value of savings and the internal rate of return require that cash flows be discounted.

Life Cycle Cost

Life cycle cost takes into account all the costs and savings over a project's life. Some of the major costs would be research and development,[1] procurement costs, operating and support costs, including fuel costs. If there is any salvage value, that would also be included. When examining alternative systems, the system with the lowest life cycle cost is the most desirable. Life cycle costs may be discounted or undiscounted.

Life cycle cost takes into account all the cash flows in the analysis. When comparing mutually exclusive alternatives, it provides a valid evaluation of which alternative is preferable (least costly). Although life cycle cost distinguishes among projects of different size, it does not provide an evaluation of which project produces the most return[2] for the resources invested.

Life cycle costing is useful for determining the size of a project and for determining the least costly alternative when choosing among mutually exclusive alternatives. More important, most evaluation methods use an estimate of life cycle cost as the basic source of data.

Payback

A project's payback is the number of years required to recover the initial investment from the annual savings generated by the investment. Sometimes the cash flows are discounted and a discounted payback period is calculated. The decision-maker determines a maximum acceptable payback and accepts projects which pay back the investment in a period equal to or less than the maximum.

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[1]Research funds already spent are not included.

[2]The "return" of a weapon system is the capability to meet the mission need.

The advantage of the payback method is that it is very simple to calculate and understand. It does not distinguish between projects with different project lives: it ignores all cash flows beyond the payback period. It is biased against long-range projects which generate increasing savings in the future. This works against long-range planning by concentrating on achieving short-term savings. Additionally, the undiscounted payback does not take into account the time value of money.

The discounted payback is more complicated to calculate because of the discounting involved but it takes into account the time value of resources. It still does not distinguish between projects with different lives. In other words, if two projects have equal payback periods, they are both equally acceptable even though one project may generate savings for many more years than the other.

Since the payback period is simple to calculate, it can be useful as a first crude approximation of a project's affordability. When budgets are constrained and future funding levels are very uncertain, payback can be a useful tool to emphasize those projects which recover the initial investment most rapidly.

Net Present Value of Savings

The net present value of savings, or net benefit, is the discounted value of savings minus the discounted costs. The net savings can be computed in two ways. The first is to compute the cost of each alternative and subtract it from the baseline system cost to determine the alternative with the largest net savings. The second way is to compare only the changes in the pertinent costs and benefits eliminating the need to derive the total life cycle cost for each alternative. If the net present value of savings is greater than zero, the project is economically feasible, that is, it produces more in savings than it costs.

In some of the federal manuals developed to evaluate energy conservation programs, net savings refers only to savings in energy while the cost part of the formula sums all the incremental costs of the alternatives being considered. While this may focus the analysis on energy savings, it is not correct from an analytic point of view. If a change in energy consumption leads to additional savings, lower maintenance requirements for instance, this should also be credited to the net savings. Enhanced capability should also be counted as a savings. Likewise, all increments in support requirements must be counted as a cost.

The net present value of savings is computed from the same data used in a life cycle cost comparison. It does not give the decision-maker additional information not contained in the life cycle cost comparison. However, if only increments are calculated, the computation required might be reduced. Disadvantages of this method are that it does not discriminate among alternatives which produce the same net savings but require different size investments and therefore does not evaluate the efficiency of the investment of resources.

Benefit to Cost

The benefit to cost ratio is the value of benefits (savings) divided by the total cost. Again it is important that all savings, not just energy, and all costs be included in the ratio. A project is economically feasible if the benefit to cost ratio is greater than 1. The larger the ratio the more savings generated for each dollar invested.

The benefit to cost ratio does not require additional data beyond life cycle costs and the ratio can be calculated using only increments for alternatives. When costs and savings are discounted, it gives a clear measure of those projects or alternatives which are economic and provides a measure of the efficiency of the investment: it shows which projects produce the largest savings per dollar invested.

Internal Rate of Return

The internal rate of return, as applied to government projects, is the discount rate which will equate the discounted value of savings to the discounted value of costs. The internal rate of return is found by trial and error; different discount rates are tried until one rate equates savings to costs.

This rate of return provides a measure of the return on a public project which can be compared to a required minimum rate of return. A project is economically feasible if the internal rate of return is greater than the required minimum return. The required minimum return is set by the decision-maker. For example, it might be set at the interest rate on government issued T-bills or perhaps at the rate of return earned by firms in the private sector.

The internal rate of return criterion enables the manager to choose economically feasible projects and it measures the economic efficiency of a project. There are a couple of reasons why the internal rate of return is not used on government projects more often. One is that computationally it is the most difficult method, due to the trial and error method needed. This disadvantage is reduced somewhat by the growing availability of computer software and hand-held calculators to do the computation. A second problem is that OMB has decided that federal projects will be discounted at 7 percent. While the OMB directive does not preclude calculating the internal rate of return, it would necessitate that two somewhat different analyses be presented for each project. Other problems occur with uneven cash flows and the reinvestment assumption which make the internal rate of return trickier to apply.

Linear Optimization

The methods discussed above are all capable of providing the decision-maker with information on the economic feasibility of a project. Under ideal circumstances when resources (funding, manpower and raw materials) are unlimited, the decision-maker would choose to fund and carry out all projects with positive net savings, benefit to cost ratios greater than 1, or acceptable internal rates of return. Usually resources are limited and the decision-maker must select a limited number of projects. Linear optimization or linear programming is a method to select the best, most efficient, set of projects given limited resources.

The disadvantage of using linear optimization is that it requires access to a computer. However, it does provide the optimal set of projects to accept and it will give information on the cost of adding more of the limited resource and the resulting change in the number and size of projects which can be accomplished. Although, linear optimization produces the optimal set of projects, the benefit to cost ratio discussed earlier can produce a close approximation.

SELECTING PROJECTS

All the foregoing methods provide an evaluation of the economic feasibility of a project. Payback is not recommended because it is biased toward projects whose benefits accrue early in the life of the project and can exclude projects with larger benefits if the benefits occur later in time. Life cycle cost, net savings, the internal rate of return, and the benefit to cost ratio will all identify those alternatives which are economically feasible.

In many cases, funding is limited and the decision-maker must choose a limited number of the available projects to be funded. In this instance, the interest is in choosing the alternative which yields the most benefit for the resources invested. Linear optimization was the only technique specifically directed at selecting the best combination of projects given a constrained budget, but the benefit to cost ratio also permits the ranking and selection of projects so as to produce an efficient set.

Table 3-1 summarizes the procedures for each method discussed. The methods can be applied in a more complicated way when there is interdependence, but that is beyond the scope of this report.

APPLICATION TO MAJOR WEAPON SYSTEMS

Energy enters the weapon system acquisition process as a support cost and as a potential cause for additions to the infrastructure. There should be possibilities to make energy-related trade-offs early in the acquisition process. The most obvious example is investing resources to design and acquire equipment which consumes less fuel. Equipment which conserves fuel may cost more to purchase but if the trade-off is economically efficient, it will produce more in future fuel savings than it costs in increased purchase price. The cost and savings are quantifiable and any of the foregoing methodologies can be applied.

Occasionally, acquiring fuel-efficient equipment will change the system effectiveness. If this can be quantified, (for example, four efficient aircraft can do the work of five of the original aircraft), the problem is minimal. Whenever possible, changes in effectiveness should be quantified so they can be included in the analysis. However, some changes in system effectiveness cannot be quantified easily and subjective judgment must be exercised. If the change in fuel efficiency increases system effectiveness, this should be counted as a factor favorable to the fuel efficient alternative. If the change in fuel efficiency decreases system effectiveness, the decision-makers must determine the priorities. If system effectiveness must be maintained, the energy-related trade-off, although economically feasible, is not acceptable.

TABLE B-1. RANKING PROJECTS AND ALTERNATIVES BY SELECTED METHODS

Method	Procedure	Application
Life Cycle Cost	Rank alternatives by life cycle cost from lowest to highest. Choose alternatives with lowest cost.	Used to find least cost alternative for mutually exclusive projects.
Payback	Rank projects based on payback. Select projects with shortest payback.	Not recommended.
Net Present Value of Savings	Rank from highest value to lowest. Choose projects with highest value first. Do not choose any with negative net savings.	Does not discriminate among projects of different sizes. Used to determine economic feasibility of mutually exclusive projects.
Benefit to Cost Ratio	Rank from highest to lowest. Choose projects with highest ratio first. Do not choose any with ratio less than 1.	Used to determine economic feasibility and to rank non-mutually exclusive projects.
Internal Rate of Return	Rank from highest to lowest. Choose projects with highest returns first. Do not choose any below minimum acceptable return.	Used to determine economic feasibility and to rank non-mutually exclusive projects.
Linear Optimization	Produces set of projects which yield the most benefits for resources invested.	Unlimited. Requires use of computer.